[COMMITTEE PRINT]

CARBON DIOXIDE, THE GREENHOUSE EFFECT, AND CLIMATE: A PRIMER

REPORT

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FOR THE

SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH AND ENVIRONMENT

AND THE

SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT

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September 25, 1984

LETTER OF TRANSMITTAL

Honorable Don Fuqua, Chairman
Committee on Science and Technology
U. S. House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

We are transmitting herewith a report which summarizes the status of information on the increasing atmospheric carbon dioxide concentrations and the resulting impact on the climate. This report was prepared by the Congressional Research Service.

The report, "Carbon Dioxide, the Greenhouse Effect, and Climate: A Primer", analyzes and discusses the scientific data currently available and points out that the concentration of carbon dioxide in the atmosphere is increasing. The inescapable conclusion is that additional action is needed including research.

The major value of this report is not in resolving the issue but in providing a sound background necessary to understand the scope of the issues involved.

Mr. Chairman, we would like to point out that this report adds to an existing body of material resulting from three joint hearings. We commend it to you and to other Members of the Committee.

Sincerely,

JAMES H. SCHEUER
Chairman
Subcommittee on Natural Resources, Agriculture Research and Environment

ALBERT GORE, JR.
Chairman
Subcommittee on Investigations and Oversight

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Washington D.C. 20540

LETTER OF SUBMITTAL

February 13, 1984

Honorable James H. Scheuer
Chairman, Subcommittee on Natural Resources,
Agricultural Research, and Environment
and
Honorable Albert Gore, Jr.
Chairman, Subcommittee on Investigations
and Oversight
Committee on Science and Technology
House of Representatives
Washington, D.C. 20515

Dear Messrs. Chairmen:

I am pleased to submit a report entitled Carbon Dioxide, the Greenhouse Effect, and Climate: A Primer, which was prepared by the Congressional Research Service pursuant to your request.

The report summarizes the present state of knowledge with respect to research and assessment of carbon dioxide effects, articulating the areas of emerging consensus and continuing disagreement, and focusing attention on the crucial uncertainties. Key scientific, technical, and social issues of the contemporary carbon dioxide/climate debate are identified, and the implications and options for dealing with the possible effects of carbon dioxide-induced climatic change are outlined. The report was prepared by John Justus, a Specialist in Earth and Ocean Sciences in the Science Policy Research Division.

We hope that this report will serve the needs of the Committee on Science and Technology as well as those of other committees and individual Members of Congress interested in global climate, climate futures, and the issues associated with possible carbon dioxide-induced climatic change.

Sincerely,

Gilbert Gude
Director

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Washington, D.C. 20540

CARBON DIOXIDE, THE GREENHOUSE EFFECT, AND CLIMATE: A PRIMER

Prepared for the Subcommittee on Natural Resources,
Agriculture Research, and Environment and the
Subcommittee on Investigations and Oversight
of the House Committee on Science and Technology

John R. Justus
Specialist in Earth and Ocean Sciences
Science Policy Research Division
February 1, 1984

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CARBON DIOXIDE, THE GREENHOUSE EFFECT, AND CLIMATE: A PRIMER

THE ISSUE

Might man's releases of carbon dioxide (CO_2) change the global climate and environment? The possibility of CO_2-induced climatic change has been at the forefront of thinking, writing, and speaking for many years. The question was raised at the end of the last century, crystallized 25 years ago during the International Geophysical Year, and politicized during the last decade. It has elicited increasing amounts of interested discussion and careful analysis in the scientific literature, as well as speculation in the public press with talk of cornucopias and catastrophes, of winners and losers, and of greenhouses and ice ages (see p. 2). CO_2-induced climatic change has become a focus of newspaper editorials, congressional hearings, and an international research program involving hundreds of scientists.

Despite a large number of remaining uncertainties, the importance of the CO_2 issue has been underscored by a growing consensus of climate and atmospheric scientists in academia, government, and international scientific organizations. 1/

1/ Assessments have been issued by such deliberative bodies as the United Nations World Meteorological Organization, the United Nations Environment Program, the International Institute for Applied Systems Analysis, the International Council of Scientific Unions, as well as the Board on Atmospheric Sciences and Climate, the U.S. Committee for the Global Atmospheric Research Program, and the Geophysics Study Committee of the U.S. National Research Council. Furthermore, the U.S. Department of Energy is conducting a carbon dioxide effects research and assessment program under the auspices of the U.S. National Climate Program. Work is also supported by the National Science Foundation, the Environmental Protection Agency and the National Oceanic and Atmospheric Administration.

Sun Belt climate to begin moving north

Climate change from CO_2 not to be feared

Special for USA TODAY

Warming of Earth Is Met With a Degree Of Reassurance

Academy of Sciences Notes Human Skills at Coping With Changes in Climate

By Robert C. Cowen

Humanity need not be at the mercy of the climate-changing effect of carbon dioxide (CO_2) gas released by burning fossil fuels — coal, gas, and oil. Earth's climatic destiny is making somewhat within [illegible]

That is the [illegible]

long-run[illegible]

THE WASHINGTON POST

problem until the [illegible]

[illegible] October 21, 1983

Earth Is Slowly Heating, Another Study Confirms

By Philip J. Hilts

[illegible] confirmed yesterday [illegible] probably will be [illegible]

lengthening the growing season in the North by 10 days. At the same time, drier conditions will reduce crop yields in the South by 5 to 10 percent. But damage to agriculture that [illegible]

THE NEW YORK TIMES, TUESDAY, OCTOBER 18, 1983

E.P.A. Report Says Earth Will Heat Up Beginning in 1990's

Continued From Page A1

[illegible] predictions for years, is the first warning by the government that the "greenhouse effect" [illegible]

Atmospheric Carbon Dioxide and the 'Greenhouse Effect'

Based on most likely (mid-range) scenario

Projected Emission Of Carbon Di[illegible]

40

Heating bills worldwide could go down.

THE GREENHOUSE EFFECT:

EPA Study Frets About "Unprecedented Rate Of Atmospheric Warming"

Over the past 125,000 years, the world's temperature has increased or decreased through a range of no more than 5 degrees Celsius. But by [illegible] are likely to be changes in [illegible]

Is the Earth Getting Hotter?

[illegible] sounded like nature's own apocalypse.

Hot Times for the Old Orb

Government studies warn of dramatic changes in climate

No Cause For Panic, Says National Academy Of Sciences

A watchful eye is the best tactic as CO_2 increases in the atmosphere over the next century, says a report issued today by the National Research [illegible] of Sci[illegible]

next couple of decades, the NRC argues, although it adds that the outlook is "more troubling" for farmers who depend [illegible]

Can We Delay A Greenhouse Warming?

Environmental Protection Agency

Strategic Studies Staff
Office of Policy and Resources Management
Washington, DC 20460

Life in a greenhouse

Abruptly, mankind is in the midst of one of the greatest uncontrolled experiments conceived by the mind of man.

According to various predictions, the increased CO2 might warm the Earth's climate, change precipitation and temperature regimes regionally and seasonally, and alter large-scale oceanic and atmospheric circulation patterns. Scientists continue, however, to debate when the Earth will respond and what impact this might have on mankind. Current conventional wisdom says that nothing would be done about the carbon dioxide problem until a clear signal of actual warming is detected; therefore, unambiguous detection of the predicted changes would profoundly affect the terms and credibility of the CO2 debate. This is a compound problem because a climate signal attributable in a statistically significant manner to CO2 might remain unmeasurable in the climate record until at least the turn of the century, and the climatic response, if significant, might not be of substantial magnitude until well into the next century. Although the "Why?" of the CO2 question is beginning to be understood, the "So what?" remains elusive.

WHAT IS THE GREENHOUSE EFFECT

The carbon dioxide molecule plays an important role in modifying the vertical distribution of temperature in the atmosphere by absorbing infrared radiation. The larger the concentration of atmospheric carbon dioxide, the more opaque the atmosphere is to infrared radiation emitted by the Earth's surface. The more outgoing infrared radiation trapped in the atmosphere, the higher the air temperature becomes. This absorption by the CO2 molecule of infrared radiation and subsequent elevation of air temperatures near the surface of the Earth is known as the greenhouse effect, although somewhat misnamed. Actually, a greenhouse warms its environment largely by reducing thermal losses due to convection. The warming associated with a CO2 greenhouse effect can be attributed to reducing the amount of outgoing infrared radiation lost to outer space, not to reducing convection losses.

INCREASES IN ATMOSPHERIC CARBON DIOXIDE CONCENTRATION: WHAT THE RECORD INDICATES

Carbon dioxide is a gas that is a normal component of the Earth's atmosphere. It composes about 0.034 percent of the atmosphere and represents a total of more than 700 billion tons of carbon. The essence of the CO2 issue is often characterized by a set of Northern Hemisphere atmospheric CO2 measurements compiled since 1958 at the Mauna Loa Observatory in Hawaii. These data have been universally cited and widely analyzed. They have also been subject to occasional recalibration. According to these measurements, supported by data from other measuring sites, the concentration of CO2 increased from about 315 parts per million (ppm) concentration to 340 ppm--a rise of 8 percent over the 26-year record. Currently, the worldwide rate of increase is approximately 0.3 percent per year. Less representative measurements taken earlier this century with instruments known to be of poor reliability show that CO2 concentrations in the 19th century were approximately 260 to 280 ppm. This means that CO2 concentrations have probably risen by 21 percent to 31 percent during the past 100 years.

SOURCES AND SINKS FOR CARBON DIOXIDE

During the last century and a half, and particularly in the post World War II period, global use of fossil fuels has grown markedly, and the burning of these fuels is believed to have been the principal source of increasing atmospheric CO2. At current rates of fossil fuel consumption, approximately 5 billion tons of carbon (as CO2) are released annually to the atmosphere. An important factor, however, is the amount of this CO2 that remains in the atmosphere--what the scientists refer to as the airborne

fraction. About half of the total amount of CO2 released from fossil fuels remains in the atmosphere, resulting in the measured increase in concentration. Scientists have assumed that the world ocean and both the land and marine biospheres serve as reservoirs (sinks) for the other half of this excess CO2, but the fate of this missing 50 percent is the subject of active research.

The extent to which changes in the mass of the biosphere might contribute to the observed increase in CO2 concentration continues to be discussed. Has the biosphere contributed CO2 or has it provided a sink for some of the fossil fuel carbon? The direction and magnitude of the contribution have been debated, sometimes heatedly, since at least 1976. For instance, several investigators have suggested that an appreciable net transfer of carbon dioxide to the atmosphere may result from such terrestrial biospheric changes as global deforestation and soil carbon wastage. Other investigators have concluded that there is no compelling evidence which establishes that the terrestrial biomass has decreased at a rate comparable to that of fossil fuel combustion. They propose that the regrowth of previously cut forests and the enhancement of forest growth resulting from CO2 enrichment of the atmosphere might have balanced the forest destruction during the past few decades. If these analyses are correct and the land biosphere is not a major net source of CO2, then essentially all the atmospheric CO2 increase could be attributed to fossil fuel combustion.

Some scientists report uncertainty as well as disagreement about estimates of the flux of carbon from the atmosphere to the world ocean and the marine biosphere. The ocean biota is emerging as a key element in the relationship between carbon cycle and climate through its role as a potential regulator of ocean-atmosphere carbon exchange. A better understanding of the effects

of climate on oceanic circulation, and of oceanic circulation on key biological processes regulating upper ocean concentrations of CO2 bears consideration as a goal for future research.

In a broad issue like CO2/climate, many discrete questions, once they are raised, must either be resolved or become a continuing theme of the overall debate. An improved comprehension of the roles of both the biosphere and the world ocean in the carbon cycle seems a necessary prerequisite to an evolving understanding of the CO2 question.

TEMPERATURE EFFECTS

Will the increase in CO2 cause a significant rise in globally averaged surface air temperatures, or might some currently known or some yet unknown countervailing climatic factor or feedback effect moderate the warming trend or even reverse it? If today's most widely accepted modelling results are correct, a doubling of the preindustrial atmospheric CO2 concentration (i.e., from 300 ppm to 600 ppm) could increase the average temperature of the lower atmosphere at middle latitudes by about 3° Celsius ± 1.5°C (5.4° Fahrenheit ± 2.7°F). 2/ The uncertainties involved in adequately representing in most "model" climates the processes that are known to be important in

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2/ U.S. National Research Council. Ad Hoc CO2/Climate Review Panel. Carbon Dioxide and Climate: A Second Assessment. Washington, National Academy Press, 1982. p. 6. See also, U.S. National Research Council. Carbon Dioxide Assessment Committee. Changing Climate. Washington, National Academy Press, 1983. 496 p.; and U.S. Environmental Protection Agency. Office of Policy and Resources Management. Can We Delay a Greenhouse Warming? Prepared by Stephen Seidel and Dale Keyes, Strategic Studies Staff. Washington, 1983. 1 v. (various pagings). Seidel and Keyes estimate a 2°C temperature rise would occur with a doubling of pre-industrial CO2 levels in the middle of the 21st century. By 2100, they estimate global warming would approach 5°C.

"real world" climate lead to the large range in the expected effect, and this range of ±1.5°C is only a probable error, not a precise measure of the full extent of uncertainty. These numerical climate simulation models, each of varying degrees of sophistication and complexity, are at present limited in their ability to represent accurately all elements of the climate system, to predict the response of various climate feedback effects, or to compensate for natural climatic variability. Furthermore, the doubling date itself has no magical properties. The world might undergo detectable climatic change either before or after that time. Different scenarios of future energy use yield different doubling dates, too, as would be expected.

It is important to recognize that some controversy surrounds the possible lower limit for the estimated change in surface air temperatures. Several investigators have inferred the existence of lag mechanisms or inherent reduced sensitivity of the climate system in suggesting the models are grossly overpredicting the climatic response to increasing CO2 concentrations. Nevertheless, an emerging consensus of climate and atmospheric scientists places the globally averaged temperature increase due to doubled CO2 at 2° to 3° Celsius. Lower estimates, it is explained, are based on model simulations that leave out important physical processes or scales of interaction. 3/ 4/ The conclusion that a drastically reduced climate response will result from a CO2 doubling is, at least at the present time, not widely accepted, but the possibilities bear further consideration and study.

3/ Ibid.

4/ Clark, William C. et al. The Carbon Dioxide Question: A Perspective for 1982. In Carbon Dioxide Review: 1982. William C. Clark, ed. New York, Oxford University Press, 1982. p. 24-25.

ANALYSIS AND DISCUSSION

Predicting Future Atmospheric Carbon Dioxide Levels

How much CO2 will be added to the atmosphere in future years, and at what rate, from the burning of fossil fuels and, to a lesser extent, from forest and soil carbon wastage? If it were assumed that fossil fuel combustion will be the dominant source of CO2 buildup in the atmosphere and that one-half of the CO2 so released is retained in the atmosphere, the future use of fossil fuels may then be influenced by projected future levels of atmospheric CO2. This in turn is a function of world population, economic activity, the cost and availability of energy resources, and technologies for utilizing those resources. For example, if global fossil fuel use were to remain constant (i.e., zero growth) at about today's level, the CO2 concentration in the atmosphere would not be expected to reach twice the preindustrial level until late in the 22d century. With a 4 percent per year growth rate, which corresponds to the global fossil fuel growth rate over the 1940 to 1973 period, doubling is estimated to occur in the first quarter of the 21st century. If fossil energy use were to grow 2 percent per year, the doubling would be delayed until late in the 21st century. Since 1973 and the rise in world oil prices, there has been no consistent trend in global fossil fuel use. Recent data suggest, however, that global fossil energy consumption and, hence, the rate of increase in emissions, has grown on average about 2 percent per year. If this average growth rate were to continue, with an additional (though debatable) terrestrial biospheric contribution amounting to 0.5 percent, the atmospheric

CO2 concentration is estimated to reach twice the preindustrial level sometime around the middle of the 21st century. 5/ 6/

In its October 1983 report, Can We Delay A Greenhouse Warming?, the Environmental Protection Agency (EPA) adopted a scenario whereby atmospheric CO2 levels would reach 590 ppm (double pre-industrial levels) by 2060, and a 2°C temperature rise would occur around 2040. By 2100, global warming could approach 5°C. The EPA report cautioned, however, that these estimates were particularly sensitive to the assumed temperature response to a doubling of CO2 and to the rate of increase of greenhouse gases other than CO2 (e.g., methane, nitrous oxide, and chlorofluorocarbons). By varying these factors within reasonable limits, the projected date of a 2°C warming ranged approximately from 2015 to 2095. The report noted that changes in the projected costs of alternative fuels or in fuel users' behavior (e.g., the degree of conservation in response to rising energy prices) have almost no effect on the estimated timing of a 2°C temperature rise. Specifically, explained the report, scenarios reflecting significant reductions in the future cost of nuclear power and renewable energy sources, increased conservation, and expanded electrification have little influence on the date of a 2°C warming, and only a minor effect on the temperature rise in 2100. Similarly, significant reductions in the baseline costs of shale oil or synfuels, conceded the report, fail to accelerate the projected 2°C warming and have only a minor effect on the estimated global warming in 2100. The EPA concluded, therefore,

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5/ Ibid., p. 16 - 17.

6/ U.S. Council on Environmental Quality. Global Energy Futures and the Carbon Dioxide Problem. Washington, U.S. Govt. Print. Off., 1981. p. 5-6, 32-51.

that substantial momentum is built into the temperature trends, due to the effect of other greenhouse gases and to the difficulty in changing fuel use patterns. 7/

The Detection Problem: Finding the Signal in the Noise

Efforts to detect, through actual observation, an unambiguous signal of the CO2-induced climate response predicted by current models are important for both scientific and policy aspects of the carbon dioxide question. First, current conventional wisdom holds that nothing will be done about CO2 until, at a minimum, a clear signal of actual warming is detected. Regardless of how warranted this view may prove, it seems evident that unambiguous detection of the predicted changes would affect the terms and credibility of the CO2 debate. Second, detection studies are an important means of confirming, rejecting, or modifying models of the interaction between atmospheric CO2 and global climate.

Confidence in the CO2-climate hypothesis would be firmer and the validity of the numerical simulations verified if a clearly discernible warming trend exceeding the "noise level" of annual fluctuations in temperature becomes evident. Many studies have been conducted to identify the climatic response to increasing CO2 and, if evident, to develop an empirical estimate of the effect to help verify or contradict the model results. Other studies have sought to explain why the response predicted by the models may not yet have been detected. At present, there is no clearly accepted evidence that confirms, with any worthwhile degree of statistical significance, a CO2 signal

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7/ U.S. Environmental Protection Agency. Office of Policy and Resources Management. Can We Delay a Greenhouse Warming? Prepared by Stephen Seidel and Dale Keyes, Strategic Studies Staff. Washington, 1983, p. iv, v.

element in the climatic record. However, using the extent of recent climatic fluctuations as a measure of noise in the record, neither is it clear that the model-predicted signal should manifest itself until near or after the turn of the century. Current observational evidence does not prove that a CO2-induced climatic warming is occurring. On the other hand, it should be emphasized that the evidence does not allow rejection of CO2-climate theories either. 8/

The difficulty is that climatic change and variability occur naturally from such other causes as: solar variations, orbital relationships, volcanic aerosols, and changes in concentration of other radiatively important trace greenhouse gases (e.g., methane, ozone, nitrous oxide, and chlorofluorocarbons). These other factors could either mask or mimic a CO2-induced warming. Several pioneering efforts of late have attempted to account for the effects of such factors as part of tests for a CO2 signal, and national and international research commitments have coalesced around a need for long-term monitoring programs on which future understanding will build. 9/ 10/

In many ways the problem of first detection poses a classical dilemma. The longer one is willing to wait for an answer to the detection question, the larger could become the predicted climate change, the longer becomes the observational record, and the smaller becomes the risk of reaching erroneous detection conclusions. On the other hand, if one waits until the

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8/ U.S. Department of Energy. Office of Energy Research and Office of Basic Energy Sciences. Carbon Dioxide Effects Research and Assessment Program. Proceedings of the Workshop on First Detection of Carbon Dioxide Effects. Harpers Ferry, West Virginia. June 8-10, 1981. Washington, U.S. Govt. Print. Off., 1982. p. 9-19. (DOE/CONF-8106214, UC-11)

9/ Ibid.

10/ Clark, et al., The Carbon Dioxide Question: A Perspective for 1982, p. 5.

signal is unequivocal before doing anything, valuable opportunities may be missed and unnecessary costs incurred. How hurriedly, then, should efforts at first detection of a CO2-induced climate change proceed? The answer to this question involves an assessment of what, if any, difference such a detection would make. What actions--social or scientific--are contingent upon detection? What are the relative penalties of undertaking those actions later rather than sooner, or mistakenly rather than never? Finally, to what extent will disagreement and uncertainty over premature first detection lead to complacency when and if a CO2-induced change were assured? 11/

Effects of Increasing CO2 on People and the Environment

Analyses of the CO2 question must ultimately address the "So what?" issue: What do rising CO2 levels mean for human societies and the natural environment? What would be the consequences of a climatic warming? To what extent would the CO2-induced warming trigger changes in the climate of various regions, in the land and oceanic biospheres, in sea level, and the extent of ice and snow in the polar regions? How and where would such warming and CO2 enrichment benefit or disrupt present patterns of agriculture? Would the possible spectrum of climatic changes and other effects portend major consequences for societal development? If so, what would be the nature and balance of beneficial and harmful effects for the economic, political, and social systems of nations? Where might they occur? Some regions and some human activities could benefit, whereas others could be harmed.

11/ Ibid., p. 29, 30.

To begin with, it is important to put the climate change that could be induced by carbon dioxide into realistic perspective. Increasing CO2 may hardly be the major challenge facing humanity. Instead, it might reasonably be viewed as one of many chips that may figure in the future balance of the affairs of nations. CO2 effects may tip some scales, but this will depend largely on where other, perhaps bigger chips happen to fall. There is growing recognition that a useful evaluation of CO2 effects must weigh the influences of population growth, energy and economic development, and technical change as well. 12/

The most important effects of CO2-induced climate change will probably involve the supplies of food, fiber, and water that people seek to obtain from their environments. A longer term and probably less urgent concern is the possible effect of CO2 on human settlement patterns. But both local climate change and a global rise in sea level, if large enough, could eventually affect where and how future populations can live. 13/

A CO2 buildup implies large economic, social, and political impacts, if the model-simulated climate responses are correct, but not necessarily disaster. In fact the direct impact on crops and forest growth may be positive, allowing for technological adaptation. The common prejudgement that all environmental change is bad should be avoided. The key question is: What actions, taken when, would help to maximize the opportunities and minimize the dangers implicit in the CO2 issue? How could food, fiber, and water systems be made more adaptive to the kinds of stresses and opportunities that

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12/ Ibid., p. 32.

13/ Ibid.

a changing climate would entail? What makes these systems vulnerable to climatic disruption? 14/

One of the primary insights of recent studies on social impacts of climate change is that most strategies appropriate for dealing with hypothetical CO2-induced climate changes are also strategies appropriate for dealing with actual climate changes of the past and present. That is to say, what we would be doing if we believed the uncertain CO2 predictions is what we should be doing anyway to cope with a certain experience of drought, famine, heat waves, and growing world demands for food. This perspective is important for at least two reasons. First, it means that rational actions to increase the future resilience of food, fiber, and water systems could be justified in terms of present problems already on the social agenda. The continuing debate over alternative means to provide food security is a case in point. Second, it raises the question of which (if any) actions not justified by immediate concerns might nonetheless deserve consideration in light of questions about future CO2 effects. In other words, what aren't we doing that we should be doing if we believed the CO2 response predictions? Answers to this last question will depend on the time scale of potential CO2-induced changes relative to the time scale of relevant human actions. For example, do concerns about CO2 currently justify crash programs in plant breeding? The answer depends on whether breeding efforts can produce new strains more or less quickly than prospective climate changes will render old ones unproductive. 15/

14/ Ibid.

15/ Ibid., p. 33.

Other examples focus attention on human activities with especially long time scales that may yet be critical determinants of the resilience of food, fiber, and water systems. Needed is an objective inventory of the life cycle of various human activities. Obvious examples of long time scale activities would include transportation systems, major housing programs, toxic waste disposal, and large-scale water supply projects. These are all projects that, if initiated today, could spend much of their useful lives under conditions of a CO2-altered climate. They may, therefore, require the kinds of present decisions that could plausibly benefit from considering the CO2 question and its possible implications. Furthermore, order-of-magnitude estimates for the regional, seasonal, and transient components of the CO2 response are not available at present. Neither has a critical evaluation been performed of what actions, undertaken when, might prove feasible and effective for enhancing the resilience of agricultural and water supply systems. In large part, this failure reflects the inability of most studies to reconcile the global causes and contexts of climate change with the regional and even local arenas in which effects and actions take on real political and economic meaning for people. 16/ As an alternative to the "definitive assessment", "final document" approach, the American Association for the Advancement of Science, the World Meteorological Organization, and the International Institute for Applied Systems Analysis have increasingly advocated iterative, regional scenario analysis. Unless some better means can be devised to bridge the gap between the understanding of global CO2-climate interactions and the desire to illuminate local impacts and options, carefully crafted regional scenarios would seem to be among the logical next steps in studies of the

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16/ Ibid., p. 33, 34.

CO2 question. To begin with, these could profitably focus on the most likely and most significant implications of the CO2 question over the next 50 to 100 years. 17/

SUMMARY AND CONCLUSIONS

The increase in the concentration of CO2 in the atmosphere and the possibility of CO2-induced climatic change have become subjects of increasing interest in the media as well as in the scientific community. The buildup of CO2 is a reality, monitored with increasing precision since 1957 and inferred from much earlier dates. Indeed, about the only facts available are the actual measurements of CO2 concentration, particularly the two-decade series at Mauna Loa and the South Pole, and some fairly reliable data from the United Nations on the annual consumption of fossil fuels in industrial countries. There the confidence ends. The CO2 "question" is actually several questions, characterized by a litany of unknowns and uncertainties--of the internal transport processes in the world ocean, of the nature and timing of the climatic response, of first-order detection, of the magnitude of forest and soil carbon wastage, and of the future course of fossil fuel consumption. Yet something else emerges, too: *if* the CO2 buildup continues, *if* the big general circulation models are right about its impact on climate, and *if* the potential role of the ocean and the land and marine biospheres has not been miscalculated, *then* there is the possibility of a climate change in the next century and a half like nothing the post glacial world, and hence civilized humanity, has seen.

17/ Schneider, Stephen H. Commentary. In Carbon Dioxide Review: 1982. William C. Clark, ed. New York, Oxford University Press, 1982. p. 50-52.

The scientific community has learned enough to run up warning signals in certain cases, but not enough to quantify the dangers with adequate confidence. So, what can climate and atmospheric scientists say now? Reviewing the areas of emerging consensus and continuing disagreement, it seems useful to continue efforts to obtain solid evidence of first order detection of a clearly discernible CO2-induced warming signal; to formulate comprehensive, internally consistent scenarios of possible future socioeconomic development, energy and land use patterns, and climate; to assess the suggested implications of such scenarios for major sectors of the economy; and to estimate the transient evolution of regional climate responses for a variety of time-evolving scenarios of increasing CO2 concentrations. Analyzing a range of different scenarios for specific periods and regions is certainly one way to begin the process of identifying what activities in society and the affairs of nations could be most vulnerable to CO2 increases.

The uncertainties inherent in the CO2 problem are often cited as justification for taking no action now. But, whether CO2 builds up or not, it is known that weather and climate will continue to fluctuate. Dealing with the CO2/climate problem is one way of coping with climatic variability in general. Thus, there are incentives to reduce the vulnerability of human settlements and activities to both climatic change and variability, to begin actions to mitigate adverse CO2-induced impacts, and to take advantage of the beneficial effects. Table 1 lists some specific strategies that could help to increase resilience and mitigate the effects of global climate change. They would likely be advantageous even if no climate change were to occur. Moreover, some of these strategies might also slow the increase in atmospheric carbon dioxide. They are reviewed in the testimonies of Roger Revelle and Stephen Schneider presented July 31, 1981, to the Committee on Science and Technology of the House of Representatives.

elaborated in in detail by Kellogg and Schware in their 1981 study, Climate Change and Society: Consequences of Increasing Atmospheric Carbon Dioxide, and highlighted in the 1983 CRS Study, Carbon Dioxide and Climate: The Greenhouse Effect. 18/ 19/ 20/ 21/

TABLE 1. Strategies To Mitigate the Effects of Increased CO2, or To Help Avert the Climatic Change

	Strategies that:	
Increse resilience	Reduce CO2 emmissions	Improve choices
Protect arable soil	Energy conservation	Environmental monitoring and warning
Improve water management	Renewable energy resources	Provision of improved climate data and its application
Apply agrotechnology	Reforestation	
Coastal land use policies	Energy taxes on use of fossil fuels	Public information and education
Maintain global food reserves	Remove CO2 from flue gases after combustion	Transfer appropriate technology
Disaster relief	Weather and climate modification schemes	

18/ Statement of Roger Revelle, In U.S. Congress. House. Committee on Science and Technology. Subcommittee on Natural Resources, Agriculture Research, and Environment and Subcommittee on Investigations and Oversight. Carbon Dioxide and Climate: The Greenhouse Effect. Hearing, 97th Cong., 1st Sess., July 31, 1981 [no. 45]. Washington, U.S. Govt. Print. Off., 1981. p. 14-25.

19/ Statement of Stephen H. Schneider, Ibid., p. 31-38, 39-57.

20/ William W. Kellogg and Robert Schware. Climate Change and Society: Consequences of Increasing Atmospheric Carbon Dioxide. Boulder, Westview Press, 1981. p. 23-29.

21/ U.S. Library of Congress. Congressional Research Service. Carbon Dioxide and Climate: The Greenhouse Effect. Report no. 83-503 SPR, by John Justus [Science Policy Research Division] Mar. 31, 1983. Washington, 1983. p. 42-48.